Composite Rods as a Steel Substitute in Concrete Reinforcement

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Abstract. The current work is concerning with the development of braided reinforced composites rods for concrete reinforcement, as a steel substitute. The research study aims to understand the mechanical behaviour of composite rods reinforced by a fibrous structure – core reinforced braided fabric. Several samples of braided reinforced composite rods were produced. Polyester fibres were used to produce the braided fabric; several types of fibres, and several combinations of fibres, were used as braided fabric core reinforcement; and polyester resin was used as polymeric matrix. The mechanical properties of braided reinforced composite rods have been evaluated under tensile. The objective was to identify the type of fibre, or combination of fibres, to be used as braided fabric core reinforcement, in order to produce composite rods with mechanical properties similar to those of steel rebars.

Introduction

The concrete construction industry is dealing with a very significant challenge regarding the deterioration of structures. Nowadays a large number of bridges, buildings and other structural elements require rehabilitation and repair and its maintenance have become an increasingly serious problem. Once subjected to repeated loading and to aggressive environmental agents, concrete structures present a decrease of mechanical properties and of durability performance, being the corrosion of steel one of its most serious problems.

Many techniques have been developed to reduce corrosion of steel, such as galvanizing, epoxy coating, and others, but none of the solutions seem to be a suitable solution. The use of fibre reinforced composite rods (FRP rods) as reinforcement of concrete elements seems to be an effective solution to overcome durability problems of traditional steel reinforced concrete structures [1, 2]. The advantages of fibre reinforced composite materials over steel include the excellent corrosive resistance, mechanical properties similar to steel, high strength-to-weight ratio and excellent fatigue resistance, among others. For this reason, the replacement of steel rebars with fibre reinforced composite rods is gaining popularity worldwide.

Typically, FRP rods are produced by pultrusion, although, besides pultrusion, FRP rods can also be produced using braiding techniques [3]. Braiding is a low cost technique allowing in-plane multiaxial orientation, conformability, excellent damage tolerance and core reinforcement. Moreover, braiding allows the production of ribbed structures and a wide range of mechanical properties may be improved when the core braided fabrics are reinforced with the appropriate type of fibres [4].

Objective of the research work, experimental work and results obtained

The current research work deals with the development of braided reinforced composite rods for civil engineering applications, namely to reinforce concrete structures as a substitute of steel rebars. The mechanical properties of FRP rods, produced by braiding, are influenced by the type of fibre used as braided fabric core reinforcement, among other parameters. The objective of this experimental work is to evaluate the influence of the type of core reinforcement fibres on the mechanical performance of braided reinforced composite rods. Several samples of braided reinforced composite rods were produced using polyester fibres, for the production of braided fabrics, E-glass, carbon and HT polyethylene fibres, as braided fabrics core reinforcement, and polyester resin as polymeric matrix. Braided reinforced composite rods have been produced on a vertical braiding machine with an incorporated impregnation system. Seven different braided reinforced composite rods were produced maintaining the braided fabric structure and changing the type of core reinforcement fibre, according to Table 1. Braided reinforced composite rods were produced with a single type of core reinforcement fibre as well as with two and three types of fibres, changing the percentage of each type. Table 1 presents the percentage of each type of fibre used as core reinforcement in the total linear density of the core reinforcement.

Table 1 – Braided reinforced composite rods characteristics

Rod type	Type of core reinforcement fibre: E-Glass fibre [%]	Carbon fibre [%]	HT polyethylene fibre [%]	Rod diameter [mm]
1	100	-	-	5,50
2	77	23	-	5,27
3	53	47	-	5,75
4	-	100	-	6,40
5	50	45	5	6,00
6	52	45	3	5,98
7	75	22	3	5,78

During the curing period of the polyester resin, the core reinforcement fibres were subjected to a pre-load of 100N. In order to evaluate the mechanical performance of the different braided reinforced composite rods produced, tensile tests were carried out according to ISO 2062 standard, with a crosshead speed of 100 mm/min. A post-load of 50KN was applied to the rods prior to performing tensile tests. Table 2 presents the average values of the tensile test results obtained with each rod type.

Table 2 – Tensile test results obtained for the different braided reinforced composite rods (average values)

Rod Type	Tensile strength [MPa]	C.V. [%]	Extension at failure	C.V. [%]	Tensile strength at 0.2% [MPa]	C.V. [%]	Modulus of Elasticity [GPa]	C.V. [%]
1	485,35	60,69	0,01701	38,61	110,73	0,08	55,36	0,08
2	766,70	11,95	0,01416	12,32	157,05	3,16	78,52	3,16
3	740,41	13,44	0,01178	8,40	148,96	3,88	74,48	3,88
4	747,77	14,11	0,01183	57,36	192,58	2,67	96,29	2,67
5	679,45	9,43	0,01105	4,08	167,84	15,74	83,92	15,74
6	652,77	11,50	0,01098	12,61	162,17	3,52	81,09	3,52
7	690,99	4,44	0,01438	7,95	146,40	7,92	73,20	7,92

C.V. - Coefficient of Variation

Analysing the tensile strength, it can be concluded that composite rods type n.º 2 (77% E-glass fibre, 23% carbon fibre) present the highest tensile strength. Composite rods type n.º 3 and type n.º 4, when compared with composite rod n.º 2, presents a decrease of tensile strength of about 3%. Composite rod type n.º 1 presents the lowest tensile strength (Fig. 1).

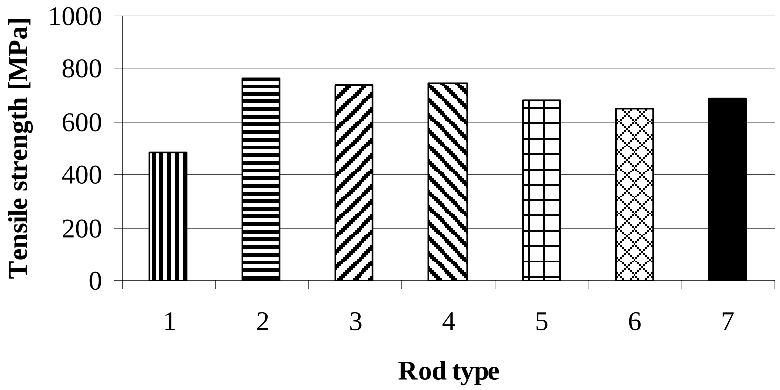

Fig. 1 - Influence of core reinforcement fibre type in braided reinforced composite rods tensile strength.

It is the braided reinforced composite rod n.º 1 (100% E-glass fibre) the one that presents the highest extension at failure value. The composite rod type n.º 6 (52% E-glass fibre, 46% carbon fibre, 3% HT polyethylene fibre) presents the lowest extension at failure (Fig. 2).

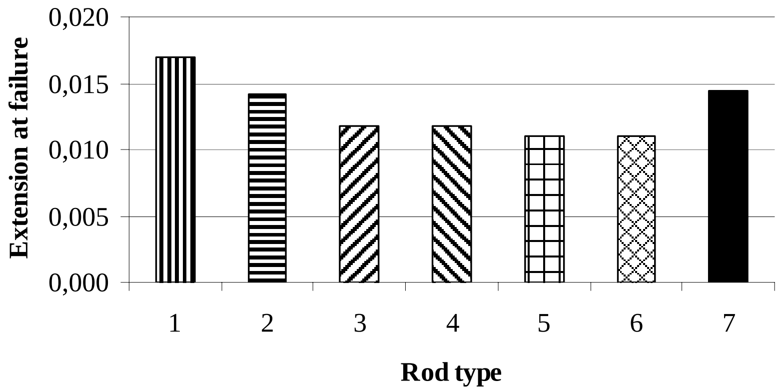

Fig. 2 - Influence of core reinforcement fibre type in braided reinforced composite rods extension at failure.

In order to identify the *offset yield point*, the yield point was defined as the stress at 0.2% plastic strain. Fig. 3 presents the tensile stress obtained, for each composite rod, at an extension of 0.002. Composite rod n.º 4 (100% carbon fibre) presents the highest yield point, while 100% E-glass reinforced composite rod (rod n.º 1) presents the lowest.

The modulus of elasticity was determined for a strain of 0.2% and Fig. 4 presents the results obtained. 100% carbon fibre reinforced composite rod (rod n.º 4) presents the highest modulus of elasticity while 100% E-glass fibre reinforced composite rod (rod n.º 1) presents the lowest.

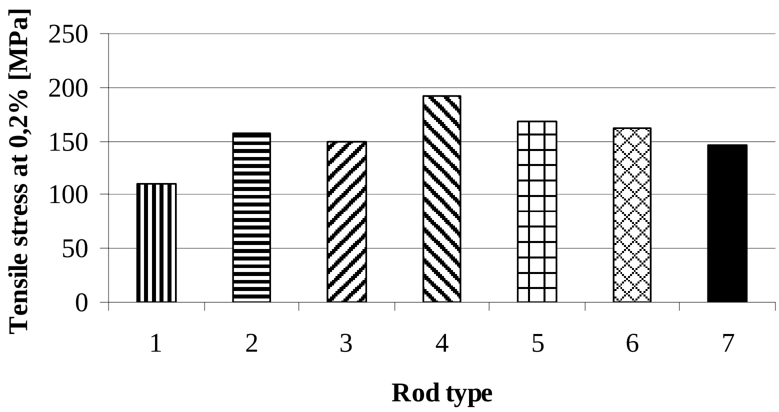

Fig. 3 - Influence of core reinforcement fibre type in braided reinforced composite rods yield point.

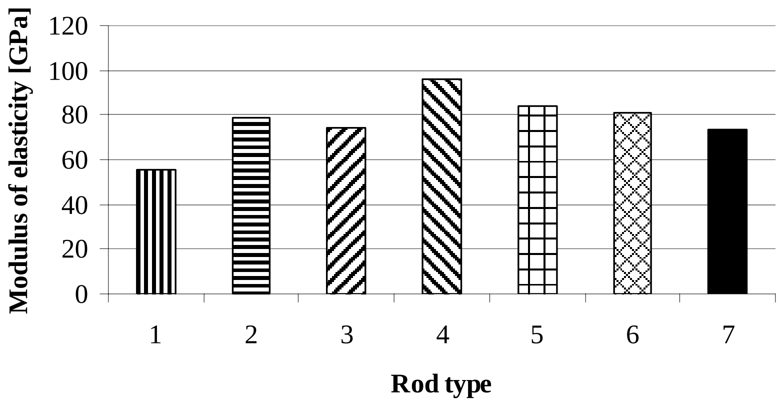

Fig. 4 - Influence of core reinforcement fibre type in braided reinforced composite modulus of elasticity.

Braided reinforced composite rod tensile performance ranking

In order to identify which is the braided reinforced composite rod that presents the most interesting tensile performance, a classification criterion was defined. Thus, was established a score from 1 to 7, namely, for the best and worth tensile performance in each parameter evaluated (Table 3). Therefore, the composite rod that presents tensile performance according to the objectives envisaged is the one that presents the smallest total score. The composite rod that presents the highest total score value is the one which tensile performance is less interesting, among the composite rods produced.

Table 3 – Braided reinforced composite rods score board.

Rod Type	Tensile strength [MPa]	Extension at failure	Tensile stress at 0.2% strain [MPa]	Modulus of Elasticity [GPa]	Total Score
1	7	7	7	7	28
2	1	5	4	4	14
3	3	3	5	5	16
4	2	4	1	1	8
5	5	2	2	2	11
6	6	1	3	3	13
7	4	6	6	6	22

As Fig. 5 shows, braided reinforced composite rod n.º 4 (100% carbon fibre) presents the most interesting tensile performance while braided reinforced composite rod n.º 1 (100% E-glass fibre) presents the less interesting. In composite rods n.º 2 and n.º 7, presenting the same quantity of E-glass and carbon fibres, the presence of HT polyethylene decreases significantly the tensile behaviour of the rod. For composite rods n.º 3, n.º 6 and n.º 5, with the same quantity of E-glass and carbon fibres, the presence and increasing of HT polyethylene fibre promotes an increasing of the rod tensile performance.

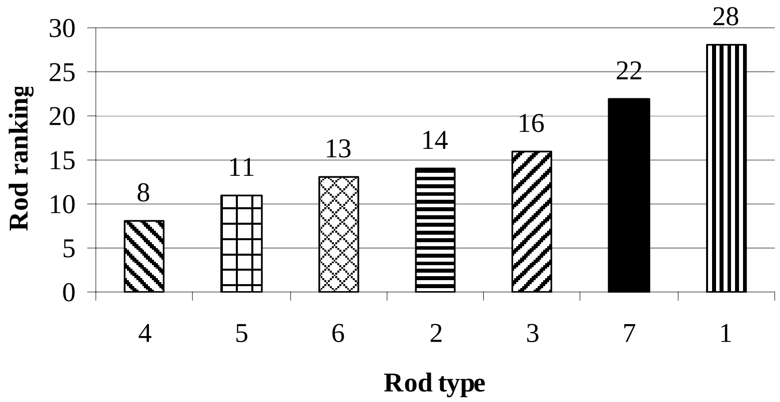

Fig. 5 – Braided reinforced composite rod tensile performance ranking.

Conclusions

It is the composite rod, reinforced by 77% E-glass and 23% carbon fibres, the one that presents the highest tensile strength. The lowest tensile strength is presented by the composite rod reinforced by 100% E-glass fibre. Analysing the extension at failure parameter, it is the composite rod reinforced by 52% E-glass, 46% carbon and 3% HT polyethylene the one that presents the lowest extension at failure, being, once again, the composite rod reinforced by 100% E-glass fibre the one that presents the highest value. The composite rod reinforced by 100% carbon fibre, is the composite rod that presents the highest yield stress and, therefore, the highest modulus of elasticity. Composite rod reinforced by 100% E-glass fibre presents the lowest values in both parameters. Based on the braided reinforced composite rod score board, the composite rods that present the best tensile performance are those who present the lowest quantity of E-glass fibre. Among the composite rods with the same quantity of E-glass and carbon fibres, the composite rod with highest percentage of HT polyethylene is the one that presents highest tensile performance.

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